

REMARKS

Favorable reconsideration is respectfully requested in view of the foregoing amendments and following remarks.

The specification has been reviewed and substitute specification is presented to correct minor typographical errors.

Attached hereto is a marked-up version of the changes made to the specification by the current amendment. The attached pages are captioned "**Version with markings to show changes made.**" No new matter is added.

Claims 1-20 have been cancelled without prejudice and replaced with new claims 21-40, respectively. The new claims are supported by the original claims. New claims 21-22 correspond to original claims 1-2, respectively. New claims 23-24 correspond to original claim 3. New claims 25-27 correspond to original claim 4. New claims 28-31 correspond to original claim 5. New claims 32-36 correspond to original claim 6. New claims 37-40 correspond to original claims 7-10, respectively.

Turning to the Official Action, claims 1-6 and 7-20 are objected to because of the informality "characterized in that".

This ground of objection is overcome by the wording of the new claims which omit the objected to terminology.

Claims 7-10 are rejected under 35 U.S.C. §112, second paragraph, as being indefinite for the reasons set forth.

This ground of rejection is deemed to be overcome by the wording of new claims 37-40, respectively, which recite an active step.

Claims 7-10 are rejected under 35 U.S.C. §101 on the basis that the "use" claims are improper under U.S. practice.

This ground of rejection is deemed to be overcome by the wording of new claims 37-41, which have been rewritten in conformance with U.S. practice.

Claims 1, 2, 4, 5, 12, 14 and 16 are rejected under 35 U.S.C. §102 as being anticipated by Van Looij et al. This ground of rejection is respectfully traversed as applied to the wording of the new claims.

The cited patent relates to endothermic and autothermic reforming of hydrocarbons/methane. The special feature of this patent is that it specifies the use of small catalyst particles, i.e., less than 10 nanometers, and various kinds of catalyst for the production of H₂ and CO, and possibly of CO₂.

There is no disclosure or suggestion in the cited patent of producing a CO₂ rich gas stream together with a H₂ rich gas stream according to claim 21.

There is further no description or suggestion in the cited patent of the claimed method which involves subjecting a gas mixture of natural gas and H₂O to a one step reforming reaction under super critical heat and pressure conditions for water, to form a reformed gas mixture. Although the cited reference discloses a reforming reaction at a temperature of 500°C and a pressure of 20-30 bar, such conditions are not super-critical operating conditions for water. See for example the Examples 1-2 on pages 4-6 of the substitute specification, particularly See Table 2.

Accordingly, this ground of rejection is deemed to untenable and should be withdrawn.

Claims 3, 11, 13 and 15 are rejected under 35 U.S.C. §103 as being unpatentable over Van Looij and further in view of Pagani. This ground of rejection is respectfully traversed as applied to the wording of the new claims.

The rejection is respectfully submitted to be untenable, because the Examiner has failed to point out any teaching of the prior art which would have motivated one of ordinary skill in the art to combine the teachings of the two sided references. The Examiner takes the position that "it would have been obvious to one of ordinary skill in the art" to modify the teachings of one reference in view of the other reference. However, the Examiner has failed to point out any teaching in the prior art which would have provided the necessary motivation to one of ordinary skill in the art to combine these selected teachings.

Moreover, the combined teachings of the cited references still fail to disclose or suggest a method for producing a hydrogen rich and CO₂ gas stream, which includes a step of subjecting a

mixture of natural gas and water to a one step reforming reaction under super critical temperature and pressure conditions for water.

Moreover, the Examiner alleges that both references are directed towards methods for producing gas streams comprised of carbon dioxide and hydrogen. However, the primary reference to Van Looij is primarily directed to producing gas streams of carbon monoxide in hydrogen.

Taking the teachings of the cited references into consideration, it is respectfully submitted that one skilled in the art would not have been motivated to arrive at the method according to claim 21.

Lastly, claims 6 and 17-20 are rejected under 35 U.S.C. §103 as being unpatentable over Van Looij et al. in view of Pagani and further in view of Kapoor et al. This ground of rejection is respectfully traversed as applied to the new claims.

The Van Looij and Pagani references fail to disclose or suggest the subject matter of the rejected claims for the reasons discussed above.

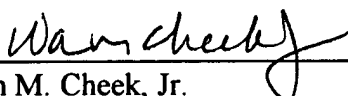
Regarding Kapoor et al., this patent was also cited in Applicant's parallel European patent application as a primary "D1" citation. In general this U.S. patent concerns the use of the exhaust gas from the furnace as a (partial-) feed to a reformer. Applicant's patent application does not describe this kind of a feed. Further, from the text of this citation it appears that a highly pure hydrogen gas is produced. According to this invention, however, there is no need for a highly pure hydrogen for the power generation. Based on this, Applicant considers the cited U.S. patent not to be relevant.

In view of the foregoing, it is believed that the application is now in condition for allowance, and such allowance is solicited.

Respectfully submitted,

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Method for preparing a H₂-rich gas and a CO₂-rich gas at high pressure

[0001] The present invention comprises a method for production of a CO₂-rich gas for injection purposes or to be deposited, and a hydrogen-rich gas, and use thereof.

[0002] It is commonly assumed that the greenhouse effect and the climate on earth are closely connected to human made emissions of CO₂. These emissions are primarily formed by combustion of coal and hydrocarbons, e.g. by generation of heat and electric power. A desirable goal is therefore to reduce the emission of CO₂ to the atmosphere.

[0003] It is known art to reduce the emission of CO₂ from combustion of natural gas, e.g. by gas reforming and shift technology for preparation of a mixture consisting of hydrogen and carbon dioxide. These components are then separated, whereafter hydrogen is used as fuel in a gas turbine and carbon dioxide is deposited after compression to desired pressure. The deposition can be made on the bottom of the sea or in geological reservoirs. The reservoirs can also contain hydrocarbons. The above mentioned technique is e.g. described in Teknisk Ukeblad No. 16, page 8, 1998.

[0004] Known art comprising gas reforming and shift technology as described above is very expensive and at the same time gives less energy yield than a conventional, modern gas power plant.

[0005] US 3,652,454 describes preparation of CO₂ and H₂ from a gas stream containing CO by an improved continuous catalytical shift reaction at high pressure. The reaction takes place in one or more shift reactors at a superatmospheric pressure of from 35 to 250 atmospheres, and a temperature between 287°C and 537°C. The patent does not describe reforming of natural gas.

[0006] From EP 0 000 993-A1 is known a method for preparation of ammonia by means of a primary and a secondary catalytic reforming of an hydrocarbon stream at superatmospheric pressure. From the primary catalytic reforming the ratio of steam to carbon is from 2.5 to 3.5, the pressure is from 30 to 120 bar and the temperature out of the reactor is from 750 to 850°C. From the secondary catalytic reforming the content of methane is from 0.2 to 10 % by weight on a dry basis and the ratio of hydrogen to nitrogen is from 2.2 to 2.7. To the secondary reforming there is added an excess of air for preparing a gas with a higher content of methane, i.e. at a lower temperature, and/or a lower steam ratio and/or a higher pressure. In the above mentioned EP patent CO₂ is removed at a low pressure by taking out hydrogen at an elevated pressure for further use by the

preparation of ammonia.

[0007] EP 0 289 419 describes a catalytic steam reforming of hydrocarbons for preparing hydrogen in an ammonia process. The catalytic steam reforming takes place at a pressure from 25 to 120 bar, a temperature from 800 to 1000°C and at a ratio of steam:carbon of 1.8-2.5. The process is operated in such a way that there are less than 0.3% impurities in the H₂-rich gas which is to be used for production of ammonia. The present invention allows a higher content than 0.3% of CO, CO₂ and CH₄ in the H₂-rich gas stream.

[0008] CA 868,821 describes preparation of synthesis gas by steam reforming of hydrocarbons in a gas and a liquid at 50-250 absolute atmospheres, preferably 160 abs. atm. for production of ammonia and methanol.

[0009] Known art does not deal with a one step process for production of a CO₂-rich gas and H₂-rich gas under supercritical conditions for water, where a CO₂-rich gas mixture is taken out at an elevated pressure in the interval from 20 to 200 bar for injection or deposition in marine formations. The present invention involves reduced compression costs by deposition or injection in marine formations because the CO₂-rich gas mixture is taken out at an elevated pressure.

[0010] The present invention comprises a method for preparing a CO₂-rich gas stream and a hydrogen rich gas stream, the method comprising the following steps:

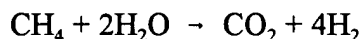
[0011] a) natural gas and H₂O are fed to a one-step reforming process for preparing a gas mixture comprising CO₂ and H₂ under supercritical conditions for water;

[0012] b) the gas mixture from a) is separated into a H₂-rich and a CO₂-rich gas stream, respectively.

[0013] Further the temperature in the reforming reactor is from about 400°C to about 600°C, and the method is also characterized by a pressure in the reforming reactor from about 200 to about 500 bar. The CO₂-rich gas stream from the separation unit is at a pressure in the interval from 20 to 200 bar. In the present invention the mixture in the reforming reactor may be passed over a catalyst bed. The reforming can also be carried out without catalyst. The present invention also concerns use of the CO₂-rich gas stream prepared according to the previously mentioned method, where the CO₂-rich gas stream is injected into marine formations. Further, the invention comprises use of the H₂-rich

gas stream prepared according to the invention, where the H₂-rich gas stream can be utilized for hydrogenation, the production of electricity and as a source of energy / fuel in fuel cells.

[0014] The following reaction takes place during the reforming:



The reforming reactor is operated at supercritical conditions for water. The temperature in the reforming reactor is from about 400°C to about 600°C and the pressure in the reforming reactor is from about 200 to about 500 bar. It is an object of the present invention that CO₂ is separated from the gas stream at a pressure of at least 20 bar and maximum 200 bar before being injected into marine formations or by deposition. The reforming reaction takes place over a suitable catalyst bed. The reforming can also take place without catalyst in the reforming reactor. It is also an object of the present invention to use H₂ made according to the method of the invention, for hydrogenation, and for production of electricity. Use of H₂ as a source of energy / fuel in fuel cells is further comprised by the present invention.

[0015] CO₂ is an acid gas, and the most widely used method to separate the mentioned gas from other non-acid gas molecules is absorption. During absorption the different chemical properties of the gas molecules are utilized. By contacting the gas mixture with a basic liquid the acid gases to a high degree will be dissolved in the liquid. The liquid is separated from the gas and the absorbed gas can then be set free either by altering the composition of the liquid or by altering pressure and temperature. For separation of CO₂ mainly aqueous solutions of alcoholamines are used. The absorption takes place at a relatively low temperature and high pressure, while stripping of the gas from the liquid is carried out at a relatively high temperature and low pressure. To liberate CO₂ from the amine phase in the stripping unit stripping steam is usually used. If the partial pressure of CO₂ in the gas into the absorber is high, e.g. higher than 15 bar, it is possible to obtain high concentrations in the amine phase, and a large part of absorbed CO₂ can be set free in the stripping unit at elevated pressure, e.g. 5-8 bar.

[0016] By the use of one or more semipermeable membrane units it is possible to achieve that molecules of different molecular weight and different properties permeate the membrane at different velocities. This principle can be utilized to separate gases. For the gas mixture in question membranes can be selected where H₂ permeates rapidly, whereas CO₂ permeates slowly, whereafter

a separation-in-part of the different gas components is achieved. By combining solid membranes and liquid membranes it is also possible to achieve a rapid permeation of CO₂, while H₂ is kept back. It can be difficult to achieve complete separation of the different gas components by using different separation methods. This is especially the case by use of membranes. For gas mixtures which are going to be burned, a partial separation of hydrogen and CO₂ will be sufficient.

[0017] In the present invention it is desirable to deposit out-separated CO₂. Large amounts of CO₂ can be deposited according to various methods, of which the three most interesting are deposition at very deep oceans, deposition in deep water reservoirs and deposition in oil reservoirs wherein the gas at the same time functions as a drive agent for enhanced oil recovery. The two last mentioned storage methods are operated commercially. In these storage forms the CO₂ gas has to be brought to high pressure for transport in pipelines to a deposition well and further to injection. The injection pressure will vary, but could be in the range 50 to 300 bar. If the CO₂ gas can be separated from the H₂/CO₂ mixture at an elevated pressure, significant compression work can be avoided, and this is the case in the present invention.

[0018] The invention is further elucidated on Figure 1. Natural gas (1) is passed from an oil/gas field, and blended with H₂O (2) before the mixture is passed to reforming at supercritical conditions. Produced synthesis gas (3) is separated at high pressure into two streams, a CO₂-rich stream (5), which is injected into an oil/gas field, and a H₂-rich stream (4), respectively. The H₂-rich stream is further used for hydrogenation, as a source of energy in fuel cells, and for production of electricity.

Example 1:

[0019] The example concerns one or more membrane units wherein the CO₂-rich gas can have a pressure approximately equal to the partial pressure of CO₂ into the separation unit, as shown in Table 1 below.

Table1

Total inlet pressure on the separation unit (bar)	Partial pressure of CO ₂ out of the separation unit (bar)
200	40
250	50
300	60

Example 2:

[0020] Supercritical conditions occur at pressures above 220 bar and temperatures above 374°C.

[0021] In this example it is described at which conditions supercritical conditions occur in the present reactor.

[0022] The relationship between temperature and pressure in the reactor in the present invention is as shown in Table 2. Supercritical conditions occur in the reactor when the values of pressure and temperature are higher than shown in Table 2.

Table 2

Pressure (bar)	Temperature (°C)
1100	354
750	356
500	362
300	368
220	374

[0023] Relationship between temperature and % fraction H₂O at 220 bar is shown in Table 3. Supercritical conditions occur in the reactor when the values for temperature and % fraction H₂O at a pressure of 220 bar are higher than shown in Table 3.

Table 3

% fraction H ₂ O (P =220 bar)	Temperature (°C)
0.95	372
0.85	365
0.75	353

The relationship between pressure and % fraction H₂O at a temperature of 374°C is shown in Table

4. Supercritical conditions occur in the reactor when the values for pressure and % fraction H₂O at 374°C are higher than shown in Table 4.

Table 4

% fraction H ₂ O (T= 374°C)	Pressure (bar)
0.95	300
0.85	400
0.75	1000



Method for preparing a H₂-rich gas and a CO₂-rich gas at high pressure.

The present invention comprises a method for production of a CO₂-rich gas for injection purposes or to be deposited, and a hydrogen-rich gas, and use thereof.

5 It is commonly assumed that the greenhouse effect and the climate on earth ~~have~~ are closely connected to human made emissions of CO₂. These emissions are primarily formed by combustion of coal and hydrocarbons, ^{e.g.} ~~i.a.~~ by generation of heat and electric power. A desirable goal is therefore to reduce the emission of CO₂ to the atmosphere.

10 It is known art to reduce the emission of CO₂ from combustion of natural gas, e.g. by gas reforming and shift technology for preparation of a mixture consisting of hydrogen and carbon dioxide. These components are then separated, whereafter hydrogen is used as fuel in a gas turbine ^e and carbon dioxide is deposited after compression to desired pressure. The deposition can be made on the bottom of the sea or in geological reservoirs. The reservoirs can also contain hydrocarbons. The above mentioned technique is ^{e.g.} ~~i.a.~~ described in Teknisk Ukeblad No. 16, page 8, 1998.

Known art comprising gas reforming and shift technology as described above is very expensive and at the same time gives less energy yield than a
20 conventional, modern gas power plant.

US 3,652,454 describes preparation of CO₂ and H₂ from a gas stream containing CO by an improved continuous catalytical shift reaction at high pressure. The reaction takes place ⁱⁿ ~~one~~ or more shift reactors at a superatmospheric pressure of from 35 to 250 atmospheres, and a temperature between 287°C and
25 537°C. The patent does not describe reforming of natural gas.

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✓ basis and the ratio of hydrogen to nitrogen is from 2.2 to 2.7. To the ~~he~~ secondary reforming there is added an excess of air for preparing a gas with a higher content of methane, i.e. at a lower temperature, and/or a lower steam ratio and/or a higher pressure. In the above mentioned EP patent CO₂ is removed at a low pressure by taking out hydrogen at an elevated pressure for further use by the preparation of ammonia.

✓ EP 0 289 419 describes ^a catalytic steam reforming of hydrocarbons for preparing hydrogen ⁱⁿ an ammonia process. The catalytic steam reforming takes place at a pressure from 25 to 120 bar, a temperature from 800 to 1000°C and at ^{of} ratio steam:carbon of 1.8-2.5. The process is operated in such a way that there are less than 0.3% impurities in the H₂-rich gas which is to be used for production of ammonia. The present invention allows a higher content than 0.3% of CO, CO₂ and CH₄ in the H₂-rich gas stream.

✓ CA 868,821 describes preparation of synthesis gas by steam reforming of hydrocarbons in a gas and a liquid at 50-250 absolute atmospheres, preferably 160 abs. atm. for production of ammonia and methanol.

✓ Known art does not deal with a one step ^c process for production ^{of a} CO₂-rich gas and H₂-rich gas under supercritical conditions for water, where a CO₂-rich gas mixture is taken out at an elevated pressure in the interval from 20 to 200 bar for injection or deposition ⁱⁿ marine formations. The present invention involves reduced compression costs by deposition or injection in marine formations because the CO₂-rich gas mixture is taken out at an elevated pressure.

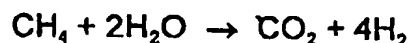
✓ The present invention comprises a method for preparing a CO₂-rich gas stream and a hydrogen rich gas stream, the method comprising the following steps:

- 25
- ✓ a) natural gas and H₂O are fed to a one-step reforming process for preparing a gas mixture comprising CO₂ and H₂ under supercritical ⁱ conditions for water;
- b) the gas mixture from a) is separated into a H₂-rich and a CO₂-rich gas stream, respectively.
- 30

Further the temperatur in the reforming reactor is from about 400°C to about 600°C, and the method is also characterized by a pressure in th reform-

ing reactor from about 200 to about 500 bar. The CO₂-rich gas stream from the separation unit is at a pressure in the interval from 20 ^{to} 200 bar. ^{In} the present invention the mixture in the reforming reactor may be passed over a catalyst bed. The reforming can also be carried out without catalyst. The present invention also concerns use of the CO₂-rich gas stream prepared according to the previously mentioned method, where the CO₂-rich gas stream is injected into marine formations. Further, the invention comprises use of the H₂-rich gas stream prepared according to the invention, where the H₂-rich gas stream can be utilized for hydrogenation, ^{for} the production of electricity and as a source of energy / fuel in fuel cells.

The following reaction takes place during the reforming:



The reforming reactor is operated at supercritical conditions for water. The temperature in the reforming reactor is from about 400°C to about 600°C and the pressure in the reforming reactor is from about 200 to about 500 bar. It is an object of the present invention that CO₂ is separated from the gas stream at a pressure of at least 20 bar and maximum 200 bar before being injected into marine formations or by deposition. The reforming reaction takes place over a suitable catalyst bed. The reforming can also take place without catalyst in the reforming reactor. It is also an object of the present invention to use H₂ made according to the method of the invention, for hydrogenation, and for production of electricity. Use of H₂ as a source of energy / fuel in fuel cells is further comprised by the present invention.

CO₂ is an acid gas, and the most widely used method to separate the mentioned gas from other non-acid gas molecules is absorption. During absorption the different chemical properties of the gas molecules are utilized. By contacting the gas mixture with a basic liquid the acid gases to a high degree will be dissolved in the liquid. The liquid is separated from the gas and the absorbed gas can ^{then} be set free either by altering the composition of the liquid or by altering pressure and temperature. For s ^{eparation} of CO₂ mainly aqueous solutions of alcoholamines are used. The absorption ^{takes} is-taking place at a relatively low temperature and high pressure, while stripping of the gas from the liquid is carried

out at a relatively high temperature and low pressure. To liberate CO_2 from the amine phase in the stripping unit stripping steam is usually used. If the partial pressure of CO_2 in the gas into the absorber is high, e.g. higher than 15 bar, it is possible to obtain high concentrations in the amine phase, and a large part of absorbed CO_2 can be set free in the stripping unit at elevated pressure, e.g. 5-8 bar.

By the use of one or more semipermeable membrane units it is possible to achieve that molecules of different molecular weight and different properties permeate the membrane at different velocities. This principle can be utilized to separate gases. For the gas mixture in question membranes can be selected where H_2 permeates rapidly, whereas CO_2 permeates slowly, whereafter a separation-in-part of the different gas components is achieved. By combining solid membranes and liquid membranes it is also possible to achieve a rapid permeation of CO_2 , while H_2 is kept back. It can be difficult to achieve complete separation of the different gas components by using different separation methods. This is especially the case by use of membranes. For gas mixtures which are going to be burned, a ^{partial} separation of hydrogen and CO_2 will be sufficient.

In the present invention it is desirable to deposit out-separated CO_2 . Large amounts of CO_2 can be deposited according to various methods, of which the three most interesting are deposition at very deep oceans, deposition in deep water reservoirs and deposition in oil reservoirs where ^ein the gas at the same time functions as ^adrive agent for enhanced oil recovery. The two last mentioned storage methods are operated commercially. In these storage forms the CO_2 gas has to be brought to high pressure for transport in pipelines to a deposition well and further to injection. The injection pressure will vary, but could be in the range 50 to 300 bar. If the CO_2 gas can be separated from the H_2/CO_2 mixture at an elevated pressure, significant compression work can be avoided, and this is the case in the present invention.

The invention is further elucidated on Figure 1. Natural gas (1) is passed from an oil/gas field, and blended with H_2O (2) before the mixture is passed to reforming at supercritical conditions. Produced synthesis gas (3) is separated at high pressure into two streams, a CO_2 -rich stream (5), which is injected into an

oil/gas field, and a H₂-rich stream (4), respectively. The H₂-rich stream is further used for hydrogenation, as a source of energy in fuel cells, and for production of electricity.

5 **Example 1:**

The example concerns one or more membrane units wherein the CO₂-rich gas can have a pressure approximately equal to the partial pressure of CO₂ into the separation unit, as shown in Table 1 below.

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Table1

Total inlet pressure on the separation unit (bar)	Partial pressure of CO ₂ out of the separation unit (bar)
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Example 2:

Supercritical conditions occur at pressures above 220 bar and temperatures above 374°C.

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In this example it is described at which conditions supercritical conditions occur in the present reactor.

✓ The relationship between temperature^e and pressure in the reactor in the present invention is as shown in Table 2. ✓ Supercritical conditions occur in the reactor when the values of pressure and temperature^e are higher than shown in Table 2.
20

Table 2

Pressure (bar)	Temperature (°C)
1100	354
750	356
500	362
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220	374

Relationship between temperature and % fraction H₂O at 220 bar is shown in Table 3. Supercritical conditions occur in the reactor when the values for temperature and % fraction H₂O at a pressure of 220 bar are higher than shown in Table 3.

Table 3

% fraction H ₂ O (P =220 bar)	Temperature (°C)
0.95	372
0.85	365
0.75	353

The relationship between pressure and % fraction H₂O at a temperature of 374°C is shown in Table 4. Supercritical conditions occur in the reactor when the values for pressure and % fraction H₂O at 374°C are higher than shown in Table 4.

Table 4

% fraction H ₂ O (T= 374°C)	Pressure (bar)
0.95	300
0.85	400
0.75	1000